The Charged Particles Stepper & Hits Collection in Calorimeters

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1-Introduction

- An Helical path is assumed for the passage of particles through matter and an helical swimmer is used for the track extrapolation through detector elements.

- However when taking properly into account the properties of energy loss through the material, as is done at generation by GEANT, there is a discrepancy with the generated events.

- The effect being more important for the dense material of HCAL, the COIL or MUDET, whereas the Swimmer gives perfects results in the TRACKER.

- A Stepper that account for energy losses in the material is discussed using Muons at different energies, e.g. 3,4,5,10,20,50 GeV/c

2-The MUCal-SDi Detector

Amount of Material in front of MuCal

EMCAL 22X0 – 0.87 Λ –190MeV lost by dE/dx

HCAL 39.5X0 – 4.08 Λ – 800MeV lost by dE/dx

The Coil 5.6 X0 – 1.27 Λ – 218MeV lost by dE/dx

Total = *67* X0 – *6.22* Λ – *1200*MeV *lost by dE/dx*

A Magnetic Field of 5 Tesla

MuCal 9 X0 – 9.6 Λ – 1600MeV lost by dE/dx

MuCal:

Outer_Radius 660.5cm(up to 550cm Instrumented)

Inner_Radius 348.5cm

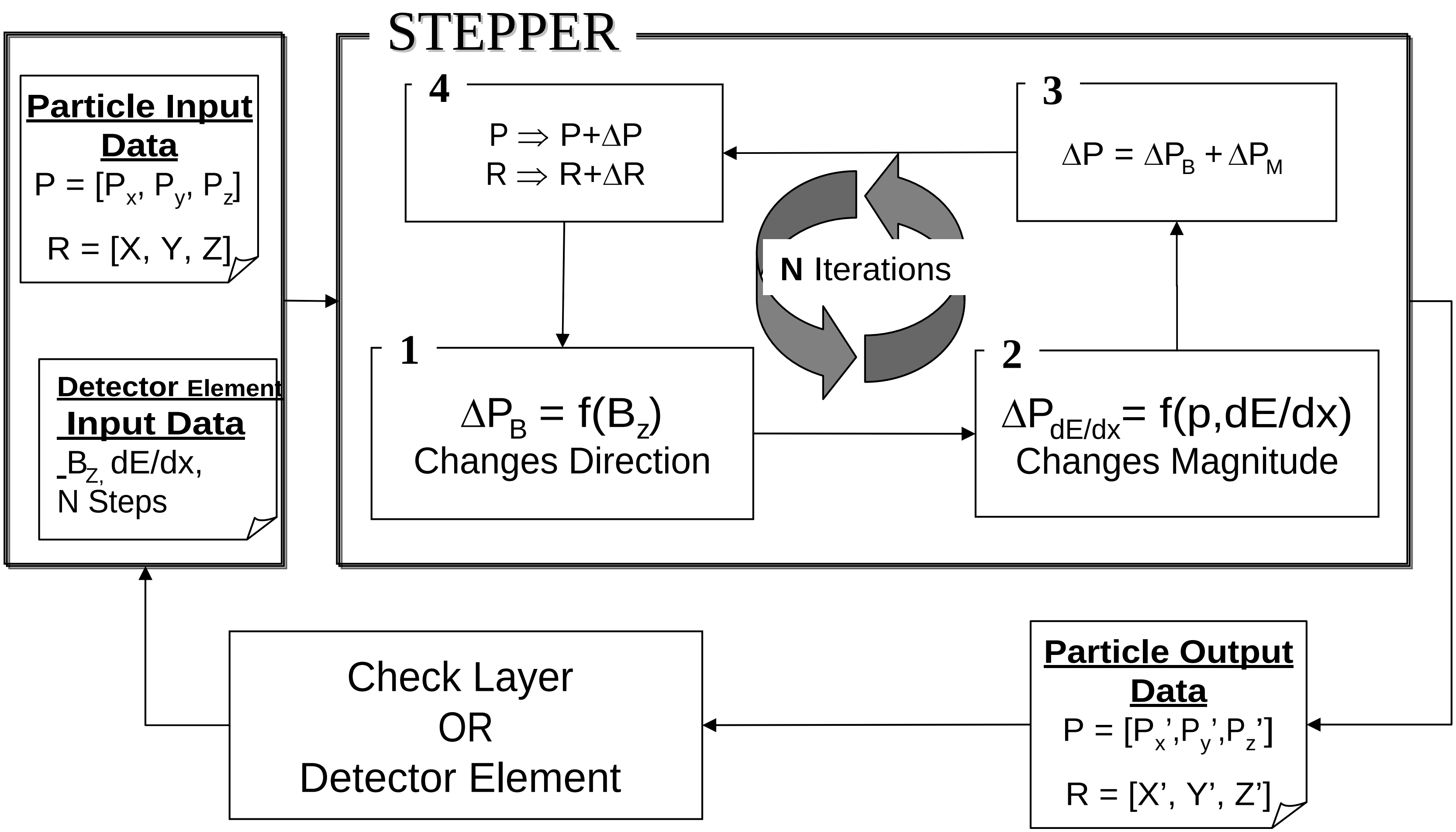
A Total 312 cm

The Unit: Fe 5cm + Gap 1.5cm RPC/gap

48 Layers /32 Layers Instrumented

80cm Fe = 16 planes

3a- Stepper Processing Flow



3b- Algorithm-The General Formula

- One starts with a particle at the interaction point (IP), at a given Position ~0,0,0, Momentum (p_x,p_y,p_z) and Mass.
- The Motion through matter in a magnetic field is given between step n and (n+1) by:

$$p_x(n+1) = p_x(n) + 0.3*q*\frac{p_y(n)}{E(n)}*clight*B_z*\Delta T(n) + \gamma_x(n)$$

$$p_y(n+1) = p_y(n) + 0.3*q*\frac{p_x(n)}{E(n)}*clight*B_z*\Delta T(n) + \gamma_y(n)$$

$$p_z(n+1) = p_z(n) + \gamma_z(n)$$

$$\gamma_i(n) = \Delta P_i^{Matter} = (\frac{dE}{di})*\frac{E(n)}{P(n)}*\frac{p_i(n)}{P(n)}*\Delta s \;;\; i = x,y,z$$

The 2nd term in p_x and p_y is the usual qv×B term due to the field B_z and the 3rd term comes from energy loss in material.
Here p_x,p_y,p_z are in GeV/c, E(n) in GeV, clight =3E08m/s, Δt in seconds.

3c- The Particle Position

The new position x(n+1),y(n+1),z(n+1), in cm, is recalculated after each step as a function of the new values px,py,pz,E and the old Position x(n),y(n),z(n).

$$x(n+1) = x(n) + \frac{p_x(n+1)}{E(n+1)} * clight * \Delta t(n)$$

$$y(n+1) = y(n) + \frac{p_y(n+1)}{E(n+1)} * clight * \Delta t(n)$$

$$z(n+1) = z(n) + \frac{p_z(n+1)}{E(n+1)} * clight * \Delta t(n)$$

ΔT(n) is the time of flight in seconds of the particle at step n .

4-The Muon Candidate

•Modification of the μ package of R. Markeloff to use a stepper to extrapolate the tracks and collect the hits.

• A set of **hits in HDCal &&EMCal** within $(3\Delta\phi,1\Delta\theta)$ bins from the track (HDCal bin=$\pi/600$; EMCal bin= $\pi/840$) is collected.

• At least **16 hits in MuCal** within $(4\Delta\phi,2\Delta\theta)$ bins from the track (MuCal bin= $\pi/150$), *in12 layers or more & a mean⩽ 2hits/layer*.

•The inclusion of dE/dx has allowed to expand the **low energy** end from 4 GeV/c down to 3GeV/c. It also improves the detection efficiency energy for Muons below 6 GeV/c.
<u>Remark:</u> We are looking only in the Barrel Detector.
Accounted by a cut in Θ, $0.95\ \text{rd}<\Theta<=2.2\ \text{rd}$

5a-Swimmer Versus Stepper In HCAL & MUDET

For particles at/above 20 GeV/c, the swimmer is representing properly the hits, but, at lower energy the effect of the energy loss on the trajectory is important.

•We will concentrate in the low energy range. Next slide represents the overlay of the hits and the track extrapolation with the swimmer for a 3 GeV/c muon. In x is given the layer number and in y the angle bin. The results are getting worse the farther we are from the Interaction Point as shown for MUDET in next to the following slide.

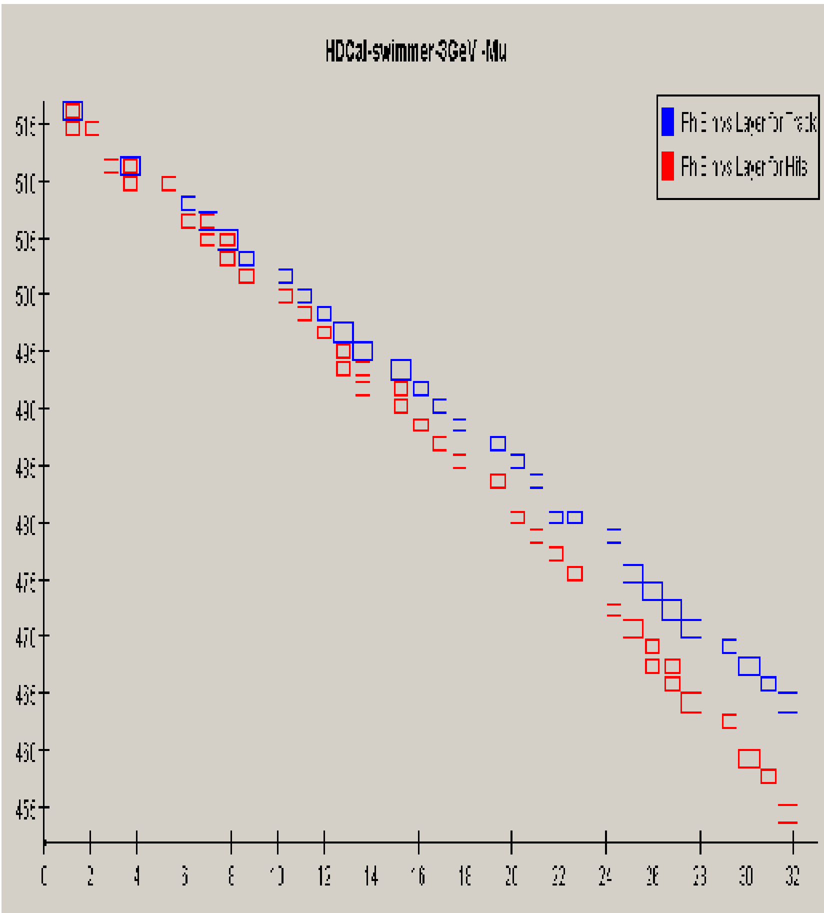
•The following slides, show a good agreement track/hits with the stepper in the calorimeters EM,HAD as well as in MUDET

5b-The Swimmer in HCal and MuDet – Φ Bin =f(Layer) Tracks versus Hits

H Cal- 1200 Φ_bins-34 Layers

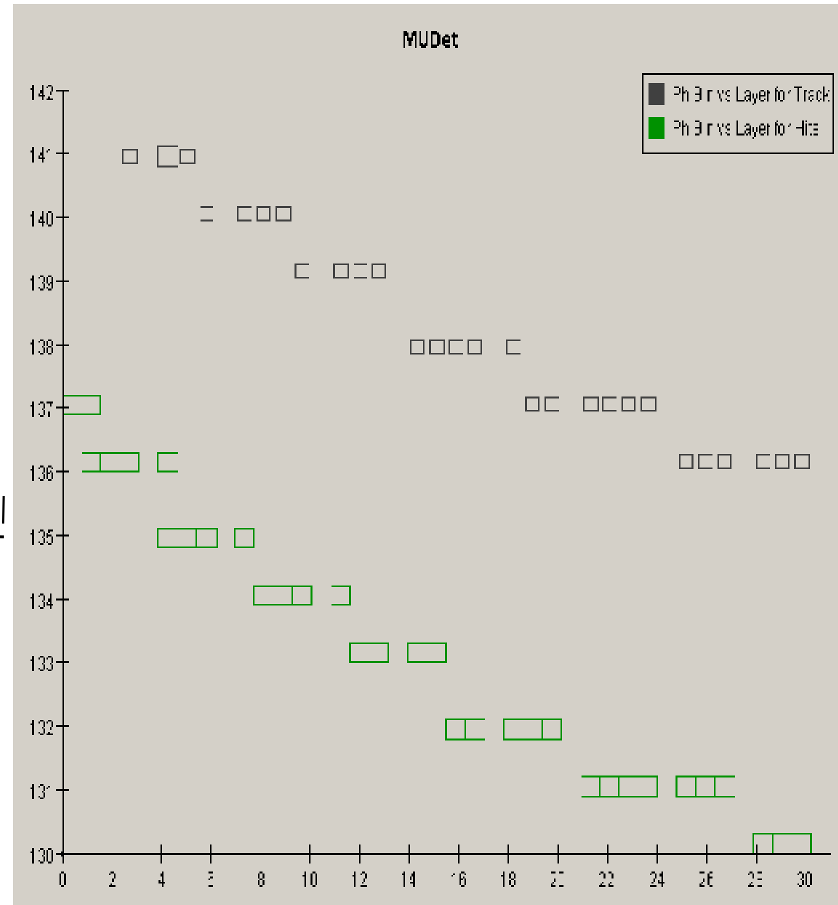
μ Det – 300 Φ_bins-32 Layers

φ_bin Number



Layer Number

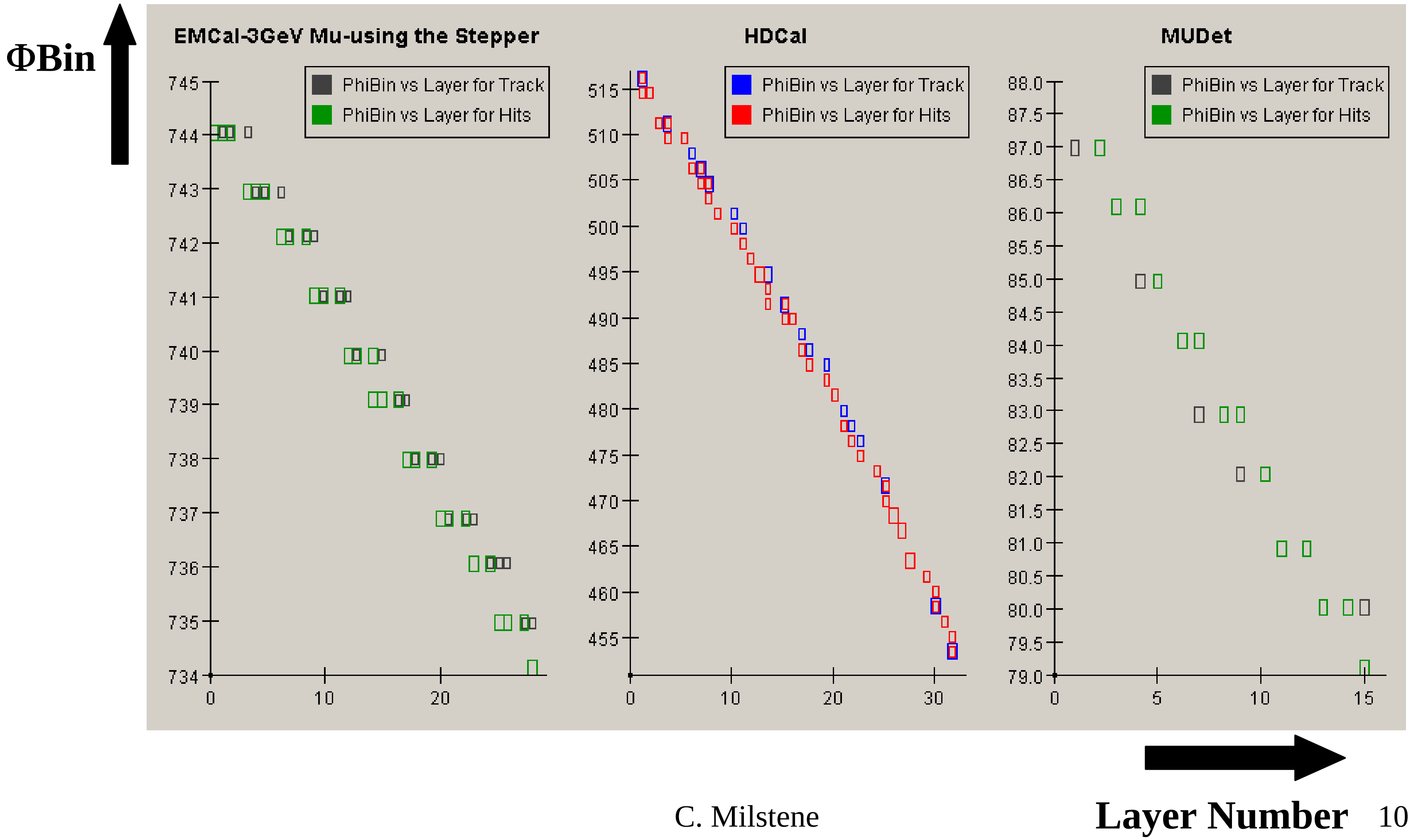
φ_bin Number



Layer Number

5c-The Stepper in EMCAL-HCAL and MUDET Angle Bin versus Layer-3GeV Muons

1680 Bins – 30 Layers **1200 Bins – 34 Layers** **300 Bins – 32 Layers**



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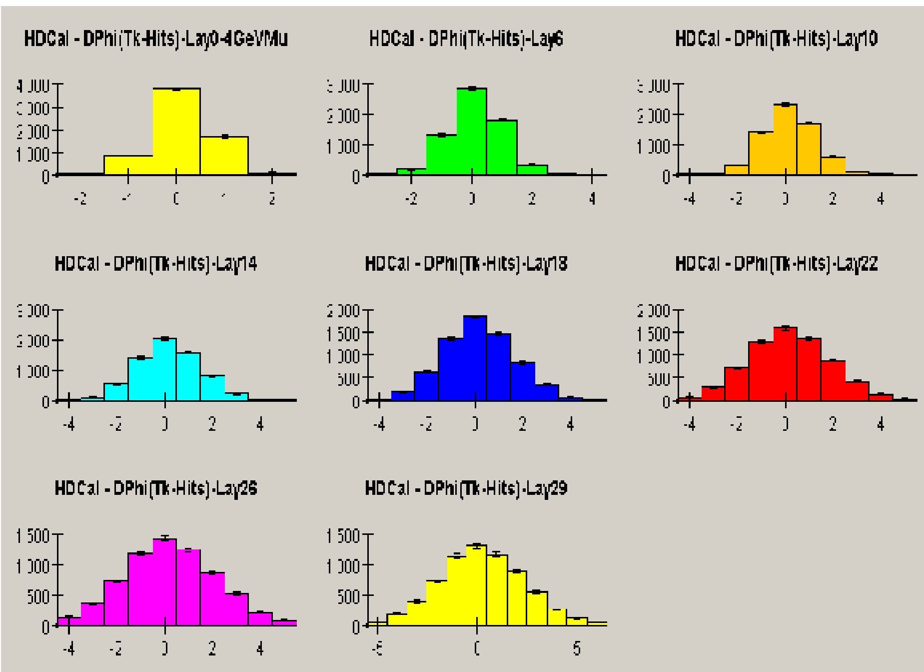
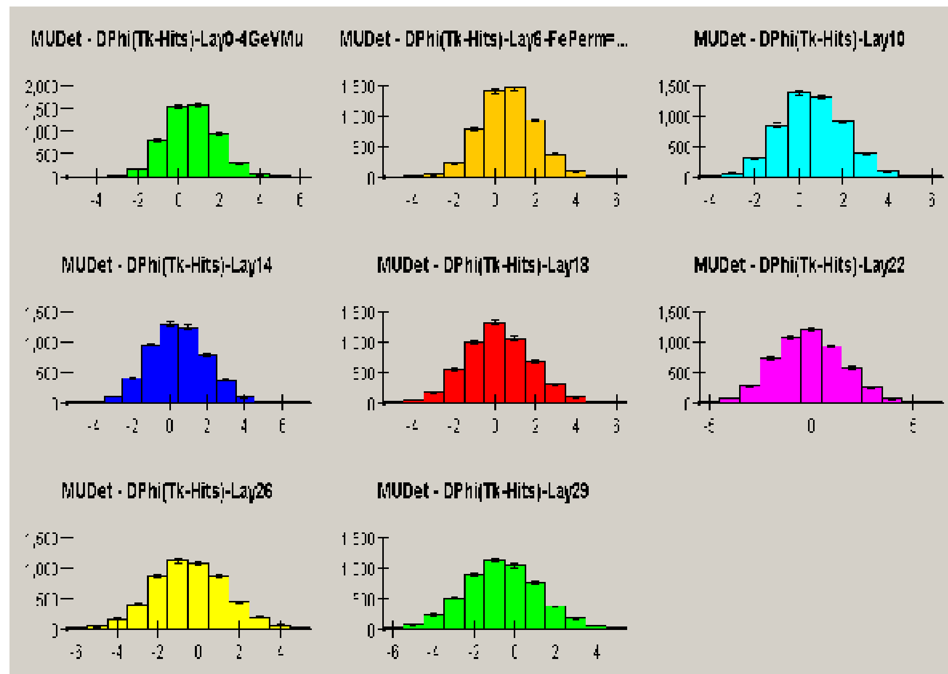
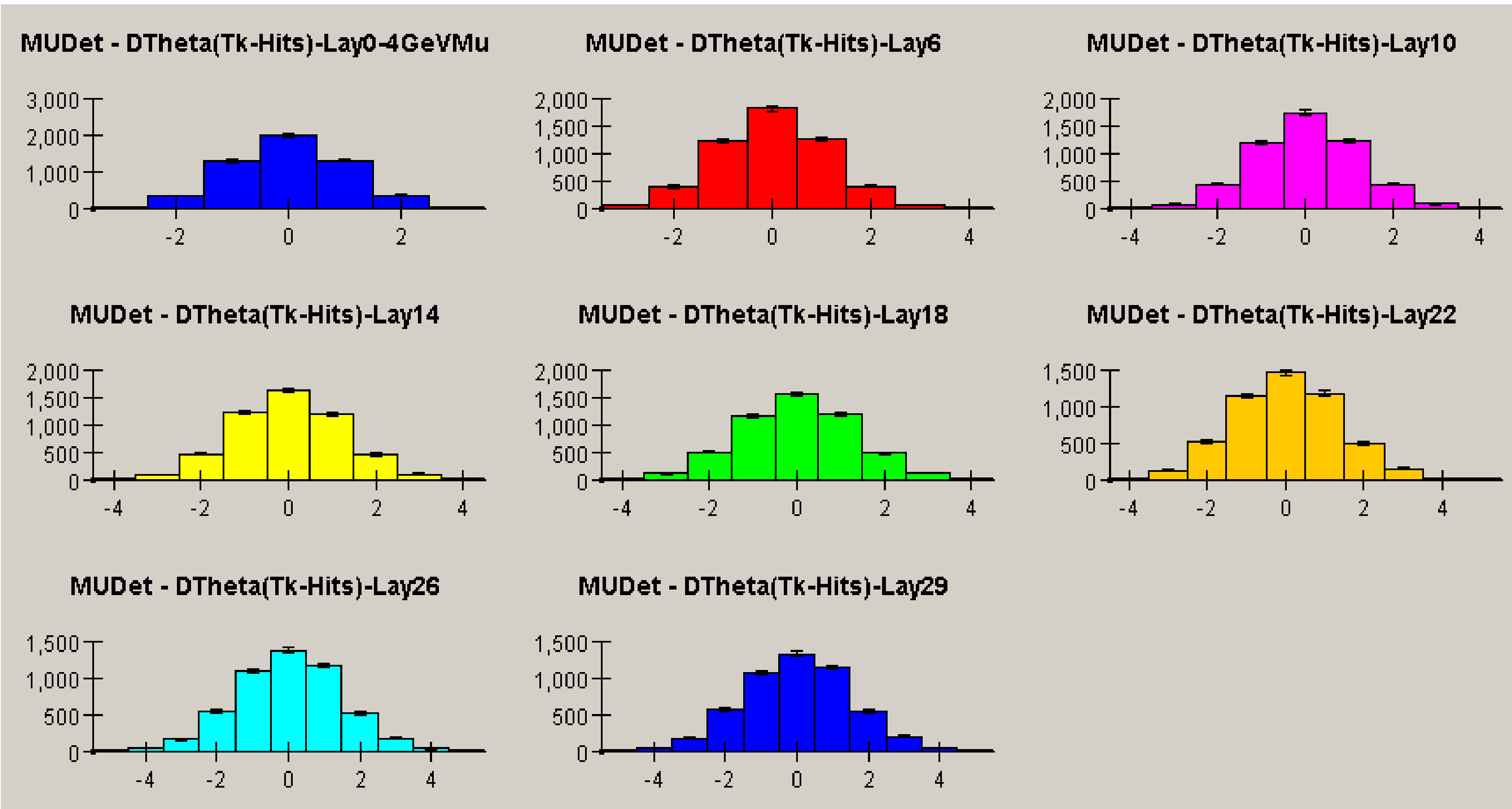
5d-The ΔF (track-hit) – 4GeV Muons
HCAL(left) MUDET(right)

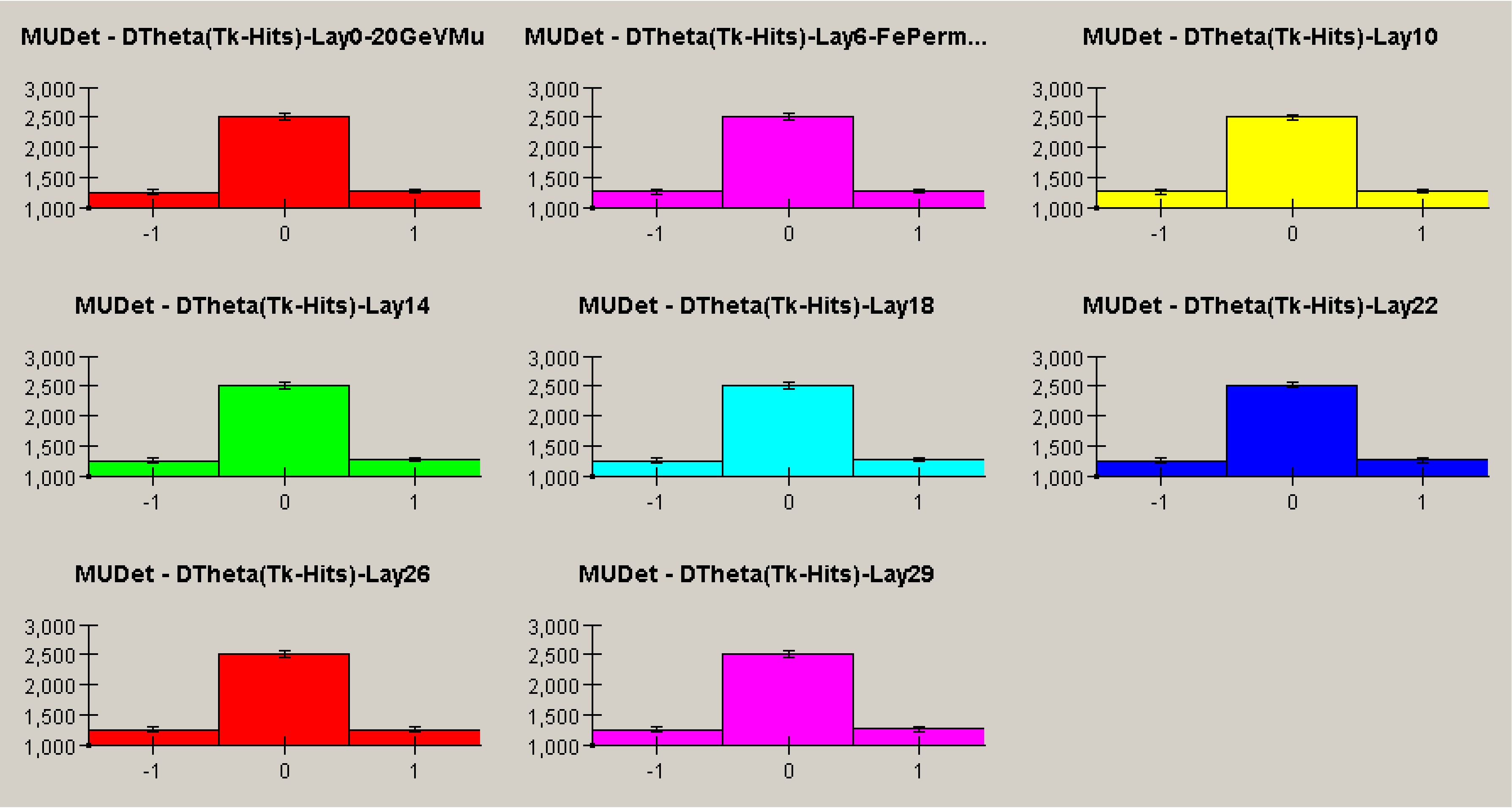




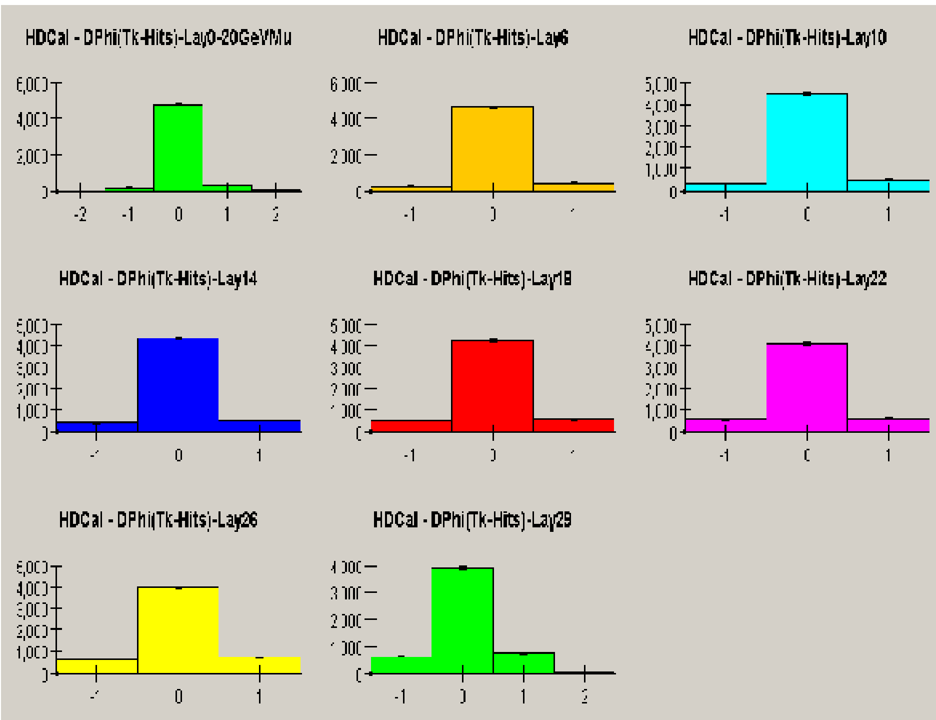
5e-The ΔT (track-hit)- 4 GeV Muons in MUDET

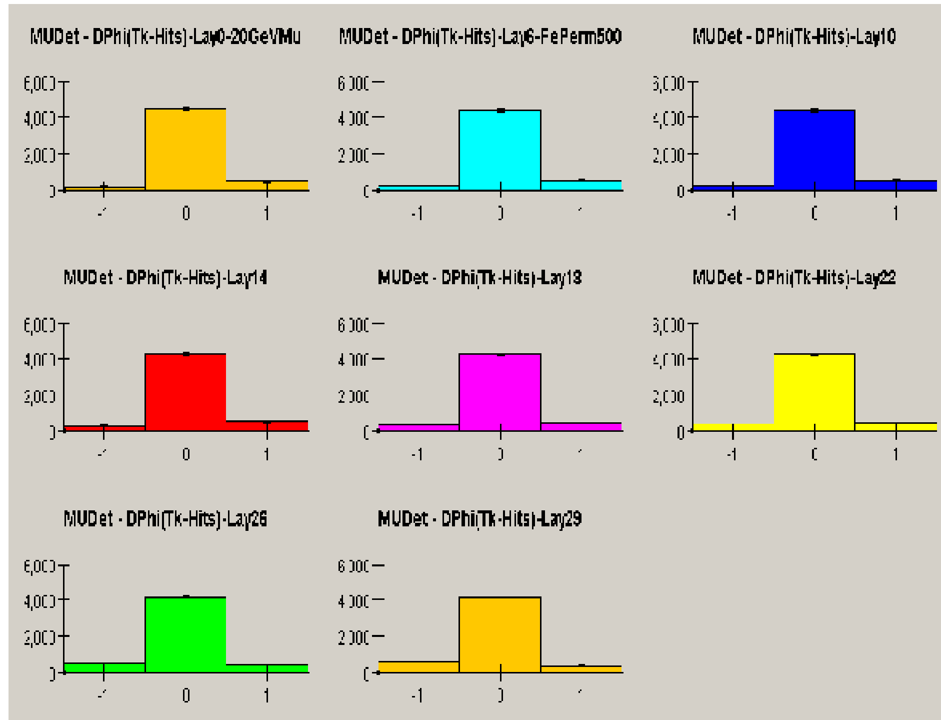


5f-The ΔT (track-hit)- 20 GeV Muons in MUDET

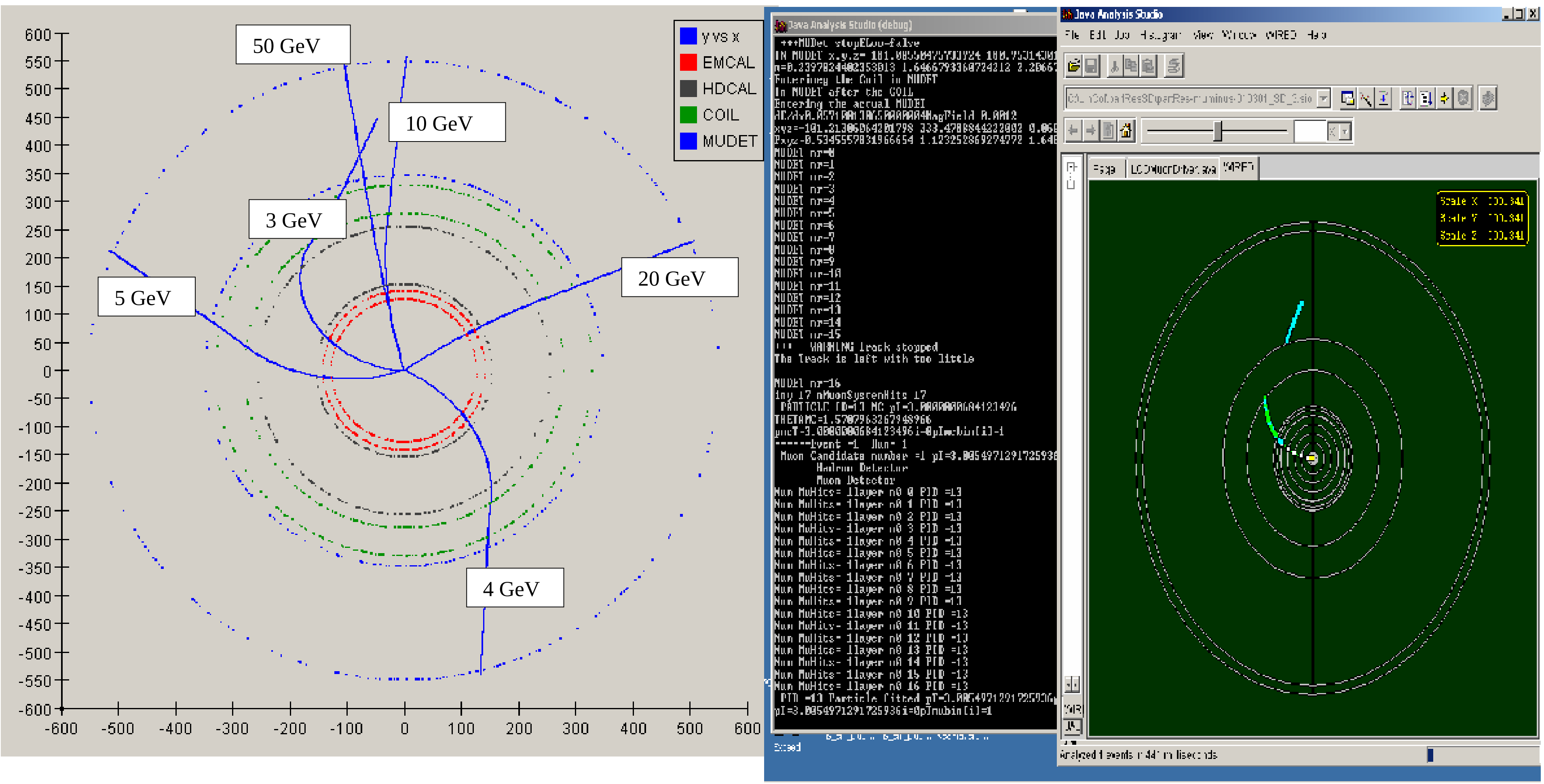


5g-The ΔF (track-hit) – 20GeV Muons HCAL(left) MUDET(right)

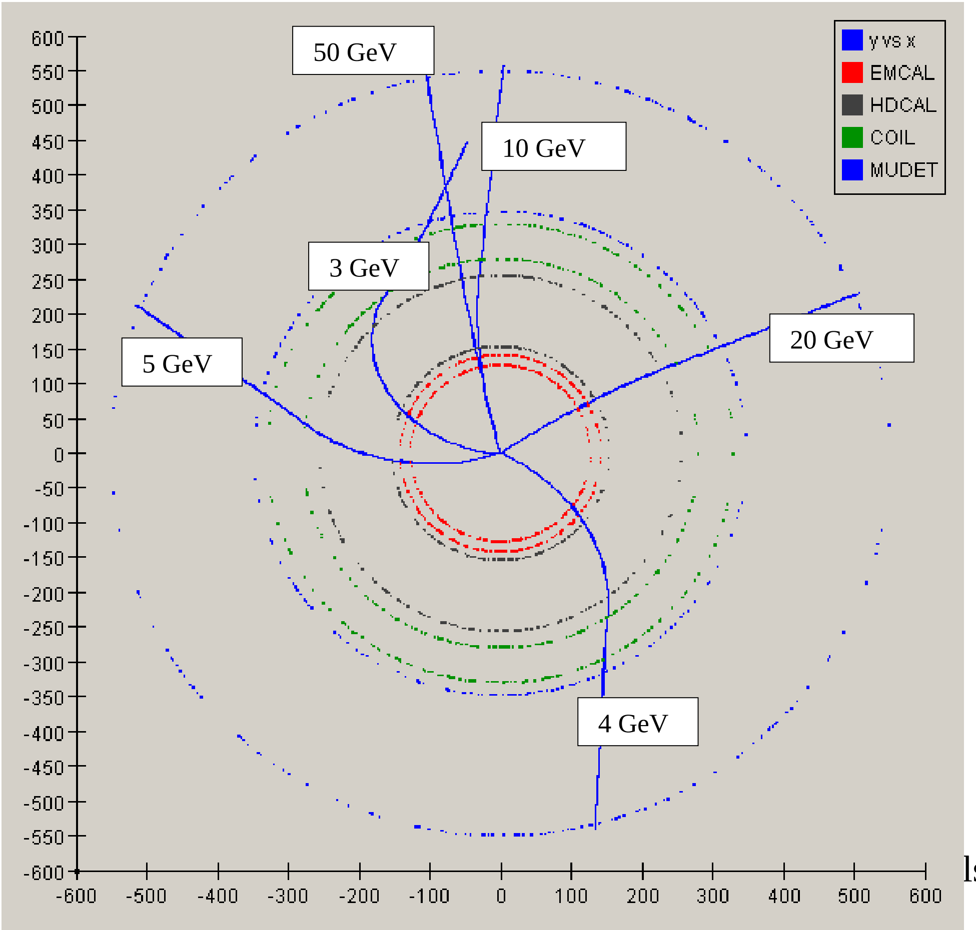


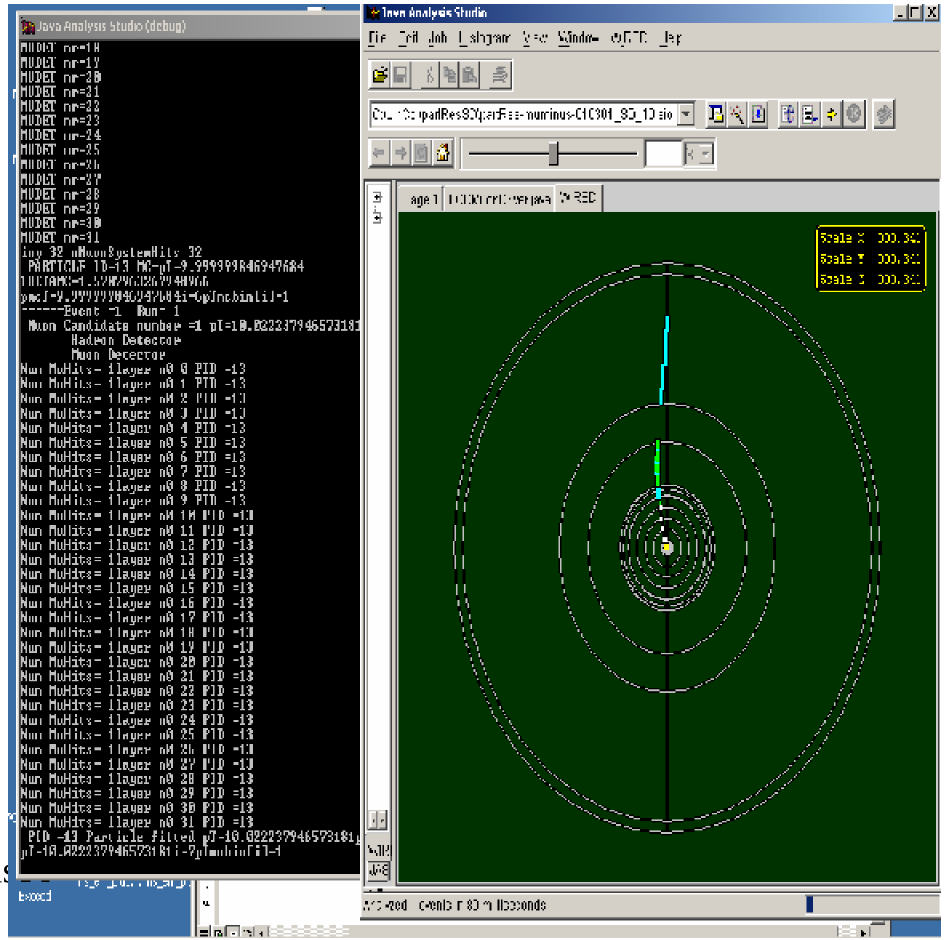


6a-Distribution (x,y) &The Event Display
3 GeV/c

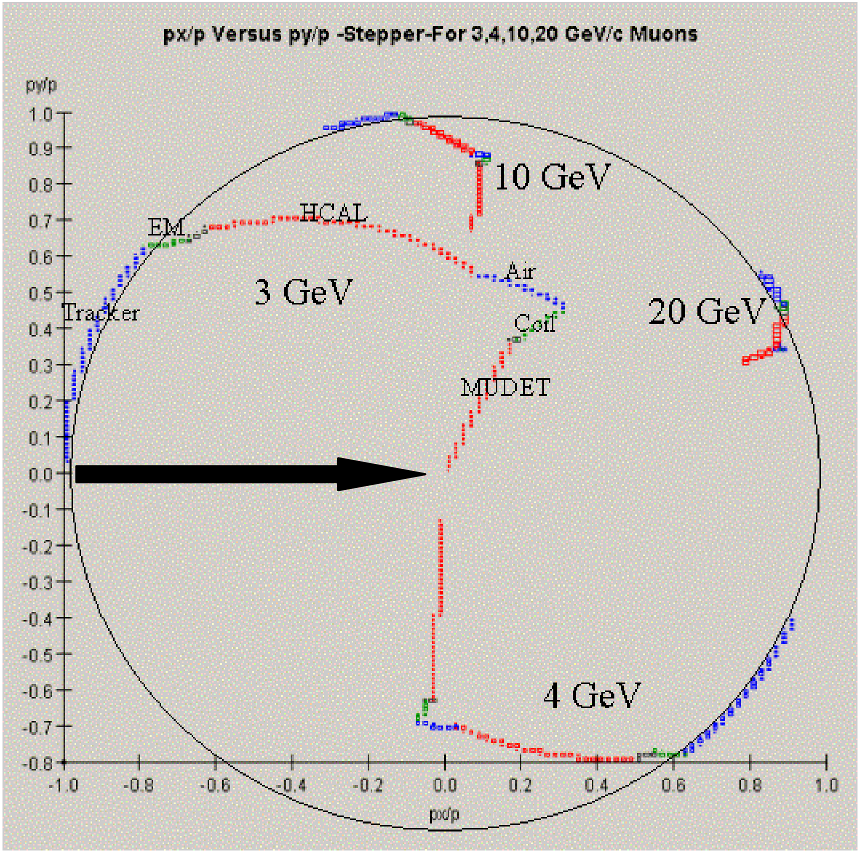


6b-Distribution(x,y) & The Event Display
10 GeV





7a-The Momentum Behavior In The Detector Components

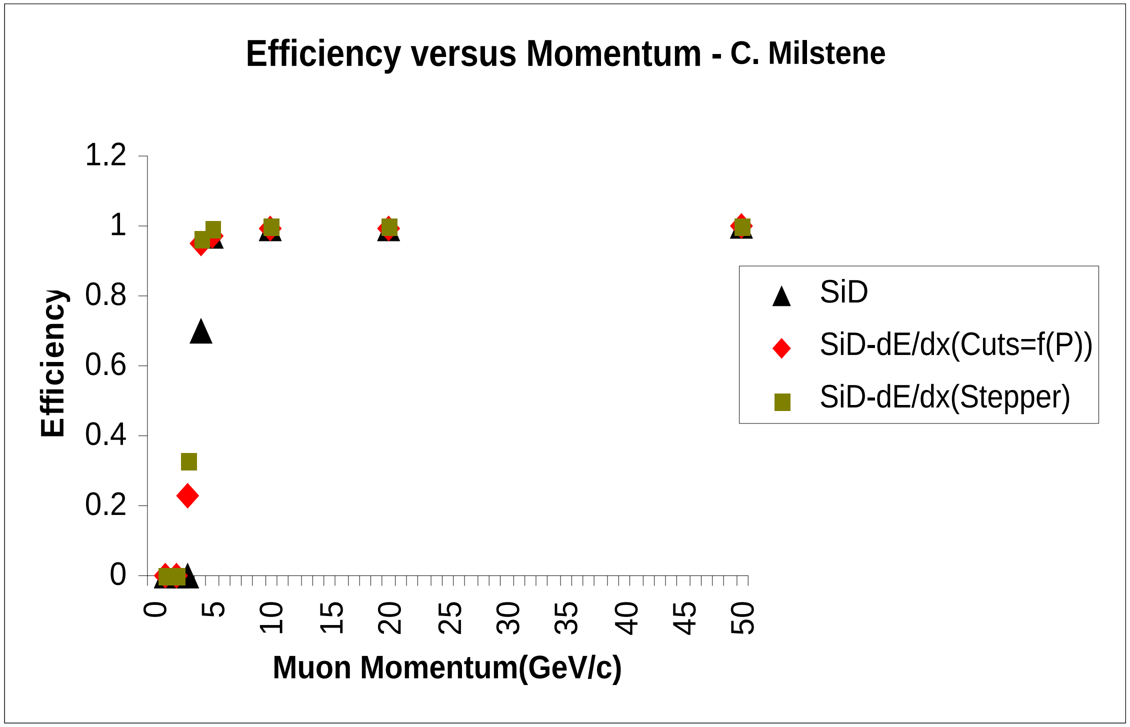


Explained in more details in the next transparency

7b-The Distribution (p_x/pStart, p_y/pStart)

WARNING: The following distributions are very different in behavior than the x, y distributions. They are in fact the COMPLEMENTARY .
One starts with the maximum momentum, e.g. 3 GeV/c, then in the tracker px and py change due to the magnetic field Bz in such a way that sqrt(p_x*p_x + p_y*p_y) stays constant, the material in the Tracker being negligible. The particle Momentum is staying at its maximum. One sees that p_x/p and p_y/p stay on the circle of radius 1.
Then, in the Calorimeters, the particle looses energy, and therefore momentum in the material encountered.
It looses more energy in HCAL than in ECAL (the S((dE/dx) *? x) being bigger). It goes on loosing energy in the COIL and in MUDET , but there, the magnetic field is inverted and smaller in magnitude. Therefore the momentum starts high and ends up at or close to zero at 3 GeV/c, and the particles often stops there in MUDET, in about 20 layers or less.
The position x, y on the other hand, was starting at radius =sqrt (x*x + y*y)~0 and increases to end up at a radius ~362 cm for a 3 GeV Muon.
The 4 GeV/c muon is left with ~10% of its energy, and the higher the Muon Momentum the smaller the change in radius (the smaller the proportion of momentum loss), as can be seen in the curves above for 10GeV/c and 20 GeV/c Muons.

8-The Muon Detection Efficiency



For 3 GeV/c Muons: The Efficiency went from: ~ 0.6% -> 23% ->33% Stepper
For 4 GeV/c Muons: The Efficiency went from: ~70% -> 95.2% ->96.2% Stepper
For 5 GeV/c Muons: The Efficiency went from: ~97% -> ~97% ->99.6% Stepper
For 10GeV/c Muons: The Efficiency went from: 98.96% -> 98.96%->99.98% Stepper
At higher energy the improvement is more subtle.

9- Conclusions

The Stepper, by inclusion of the dE/dx gives a better fit to the Muons generated with Geant, especially in the low energy range and The tracks stick to the one shown by the Event Display(coded independently) both in shape and size.
The Muon Detection Efficiency improves at low energy, reaching 96% already at 4 GeV/c.
Without the involvement of Gene Fisk this work would not have been possible, thanks are due also to Adam Para for important comments and suggestions.

Backup

The Particle Momentum

One can write for the term material dependant (details next)

$$\gamma_x(n) = \Delta Px = \left(\frac{dE}{dx}\right) * \frac{E(n)}{P(n)} * \frac{p_x(n)}{P(n)} * \Delta s$$

$$\gamma_y(n) = \Delta Py = \left(\frac{dE}{dx}\right) * \frac{E(n)}{P(n)} * \frac{p_y(n)}{P(n)} * \Delta s$$

$$\gamma_z(n) = \Delta Pz = \left(\frac{dE}{dx}\right) * \frac{E(n)}{P(n)} * \frac{p_z(n)}{P(n)} * \Delta s$$

The Particle Momentum (cont)

Moving particles lose energy in the material by dE/dx,
Approximation: dE/dx ~Constant=Ct for a path length Δs in step n

$$\Delta E = \left(\frac{dE}{dx}\right) * \Delta \mathrm{s} \ \&\& \ \Delta \mathrm{E} = \frac{\mathrm{dE}}{\mathrm{dP}} * \Delta P = \frac{P(n)}{E(n)} * \Delta P \rightarrow \Delta \mathrm{P} = \frac{\mathrm{E(n)}}{\mathrm{P(n)}} * Ct * \Delta s$$

At start of the step, momentum directions :p_x/P=a, p_y/P=b, p_z/P=c.
Due to B_z change in directions to p_x'/P'=a',p_y'/P'=b',p_z'/P'=c'
Angles at the center of the step: (a+a')/2 , (b+b')/2
One can use the center of the step to express Δp_x, and Δp_y as follow.

$$\Delta p_x = \Delta P * \frac{a+a'}{2} \ ; \Delta p_y = \Delta P * \frac{b+b'}{2}$$

And if step is small enough one can approximate
a'~a=p_x(n)/P(n), b'~b=p_y (n)/P(n)

The Time Of Flight

Below one expresses the components of the velocity as a function Of p,E and the light velocity. If d is the step size one gets for the Radii between steps n and n+1 the following relations

$$V_i(n) = \frac{p_i(n)}{E(n)} * clight\,;\; i = x, y, z$$

$$r(n+1)^2 - r(n)^2 = [x(n+1)^2 + y(n+1)^2] - [x(n)^2 + y(n)^2]$$

$$= [\{x(n) + \mathrm{v}_x(n) * \Delta T(n)\}^2 + \{y(n) + \mathrm{v}_y(n) * \Delta T(n)\}^2] - [x(n)^2 + y(n)^2]$$

$$r(n+1)^2 = r(n)^2 + 2 * d * r(n) + d^2$$

ΔT(n) is the solution of an equation of the second order.

Distribution(x,y) & The Event Display 5GeV/c